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Micromachined Travelling Wave Slotted Waveguide Antenna Array for Beam-Scanning Applications

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***Abstract*—A design of travelling wave slotted waveguide antenna array based on micromachined layers operated in the WR-03 frequency band (220-325 GHz) is demonstrated in this paper. The antenna structure remains simple and is designed to be fabricated by using thick SU-8 photoresist technology. Instead of a matched load or a back-short at the termination of the waveguide, a novel H-plane bend followed by a radiating slot is integrated in order to minimise the power reflected to the input port and achieve the travelling wave operation. It also enables broadening of the bandwidth, and keeps the high gain value of the antenna. The 8-slot linear array antenna has shown a simulated gain of 13.5 dBi in the E-plane at 300 GHz, and 30% fractional bandwidth from 240 GHz to 325 GHz. The main beam scans in the H-plane, from -25° to -6°over the bandwidth. The scanning feature is attractive for radar applications.**

Keywords*—Beam scanning, travelling array, millimeter-wave waveguides, H-bend radiating slos.

I. INTRODUCTION

Frequency scanning waveguide antenna arrays have been introduced to radar applications since 1950 [1]-[3]. To achieve frequency scanning in a conventional travelling-wave slotted waveguide antenna array, a matching load at the termination of waveguides is used to absorb the power which is not radiated, and a phase shifter to control the main beam direction [4]. Indeed, a matched load, which does provide wider bandwidth at the expense of antenna gain, is not desirable for radar applications. Also, at the millimeter-wave band, it is difficult to implement matched load and phase shifter for the antennas because of the inefficiently of shifters and the small size of the components [5], [6].

Therefore, in this paper, a novel H-bend feeds a radiating slot replacing the matched load. This H-Bend Radiating (HBR) slot has been integrated with the linear array of the slotted waveguide antenna (Figs 1and 3) instead of the matched load in order to lower the VSWR and keep the high gain value of the antenna at the designed frequencies (220-325 GHz). Also, it has been realised in this work that with the presence of the HBR slot, in addition to widening the bandwidth, a wider range of beam scanning angle can be achieved.

Due to the complicated three dimensional structure of the waveguide, the slotted waveguide antenna presented in this paper has been suited to be fabricated using 288 µm thick micromachined SU-8 photo-resist layers. Based on the previous work, this technique can confidently be used to make millimeter-wave devices with dimensional errors of only a few microns and introducing very low losses [7], [8, 9]. It is believed that the design proposed here is the highest operation frequency for any travelling wave slotted waveguide antenna.

II. DESIGN OF HBR SLOT

A single HBR slot is shown in Fig. 1and has a length (a) which is about half of a wavelength. Its width is equal to the narrow wall dimension of the waveguide. The simulated reflection coefficient of the HBR slot is less than -20 dB from 220 to 325 GHz as shown in Fig. 2. The HBR slot has been optimised using full-wave simulations (CST), and has a gain of (6.85dBi) at 300 GHz with only 0.8 dBi variation over the whole WR-03 band as depicted in Fig 2. From Figs. 2, it is important to note that the directivity and radiation pattern of the HBR slot are almost frequency independent. This behaviour is similar to half wave dipole antenna as expected [10].

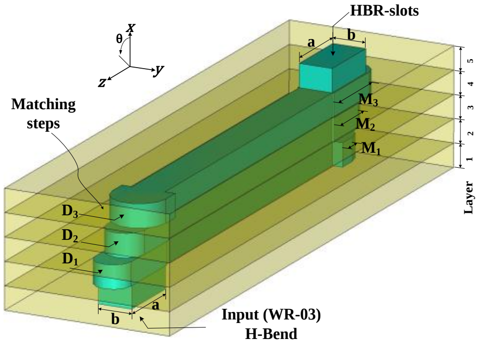

Fig. 1. Diagram of the designed HBR slot with the characterisation of the three matching steps. b=0.432 mm, d=0.96 mm, a=0.864 mm, D_1=0.699 mm, D_2=0.499 mm, D_3=0.469 mm, M_1=0.24 mm,M_2=0.60 mm,M_3=0.91 mm.

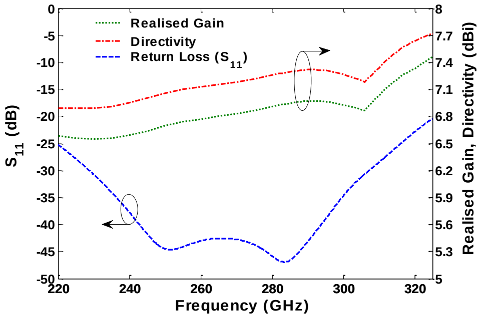

Fig. 2. Variation of S_{11}, realised gain, and directivity of the HBR slot versus frequency.

III. DESIGN OF LINEAR ARRAY WITH 8- RADIATING SLOTS AND ITS PERFORMANCE

A. Design configuration

The full travelling wave array with 8-slots in the narrow wall of the waveguide is shown in Fig. 3. In the previous design published about a standing wave array [7], the spacing between slots, was chosen to be one guided wavelength in order to feed all the slots in phase. Two grating lobes existed in the radiation pattern of the antenna due to the inter-element spacing (λ_g) which is larger than the free space wavelength [11]. However, for travelling wave array, the spacing slot does not have to be λ_g [12]-[14]. In this paper, the inter-element space is chosen to be $d = 0.78\,\lambda_g$. This spacing provides a wide range of main beam scanning. It is worth noting that the slots are not excited in phase here. Thus, a progressive phase shift is generated.

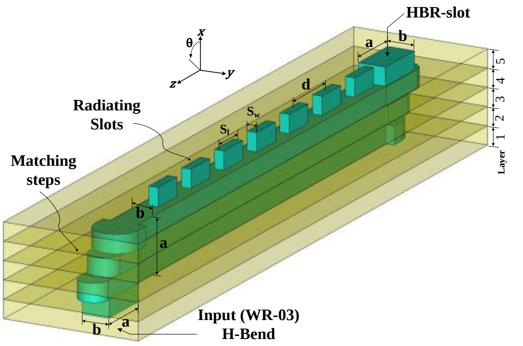

Fig. 3. Layout of an 8-slot travelling array cut in the centre of the narrow wall of the waveguide based on the micromachining layers (equal thickness t=0.288 mm). An H-plane bend is integrated with the structure to interconnect with the waveguide flange (WR-03) precisely, and an H-plane radiating slot is designed in order to cancel the reflected power to the input port. The outstanding structure in the central area represents the hollow waveguide WR-03 and slots, while the surrounding conductors are set to be transparent). a=0.864 mm, b=0.432 mm, d=0.964 mm, S_w=0.15 mm, S_l=0.55 mm.

B. Design performance

This section demonstrates the simulated performance of the designed 8-slots linear array antenna operated at 300 GHz. The simulated radiation pattern of the antenna has a main beam in the H-plane which is -13° scanned towards the input port with the existence of one grating lobe at 55° as shown in Fig. 4. The main beam scans due to the progressive phase shift produced, and the appearance of one grating lobe is because of the spacing (0.78 λg) which is still larger than half of the free-space wavelength. The simulated E-plane radiation pattern of the antenna when $(\theta_0 = 13^\circ)$ has shown 13.5 dBi gain. The side lobe level is 13.3 dB in the E-plane which is better than 6.8 dB in the H-plane. A very good matching below -10 dB from 240 to 325 GHz is observed in Fig. 5. This large bandwidth (30%) provides a wide range of beam scanning.

C. Main Beam scanning

This section describes the scanning of the main beam H-plane radiation pattern with respect to frequency. The H-plane radiation pattern from 255 to 325 GHz is investigated, and shows the main beam scanning from -25° to -6°. This means a 19° main beam scanning over 23.3 % BW.

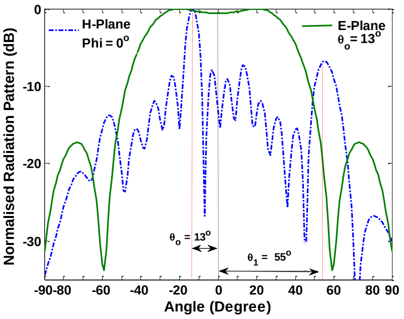

Fig. 4. Simulated radiation pattern of the 8-slots at 300 GHz.

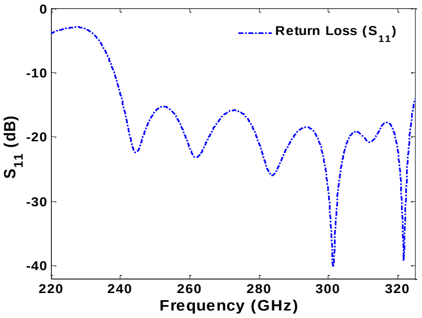

Fig. 5. Variation of return loss of the antenna versus frequency.

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